

The First Results of K2K long-baseline Neutrino Oscillation Experiment

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Abstract. The first results of the K2K(KEK to Kamioka) long-baseline neutrino oscillation experiment are presented in this talk. In 1999 7.2×10^{18} protons on target were delivered to the experiment. During this period of running there were 3 events fully contained in the Super-Kamiokande inner detector fiducial area which occurred during the beam spill timing window. In the case of no oscillations the expected number of events during this period was $12.3^{+1.7}_{-1.9}$. The near detectors located at KEK also have begun detailed measurements of neutrino interactions in water at around 1 GeV.

INTRODUCTION

The atmospheric neutrino anomaly observed by Super-Kamiokande(SK) and other recent underground experiments strongly suggests $\nu_\mu \leftrightarrow \nu_\tau$ neutrino oscillation. The allowed region of the oscillation parameters obtained by SK are in the range of $\Delta m^2 = 2 \sim 5 \times 10^{-3} \text{ eV}^2$ and $\sin^2(2\theta) > 0.88$ with 90% confidence level [1], where Δm^2 is the mass difference squared between two neutrino mass eigenstates and θ is the mixing angle between two neutrinos.

The principal goal of the K2K experiment is to confirm neutrino oscillation with a man-made neutrino beam and to measure the oscillation parameters. Fig. 1 is a schematic of the setup. We use the 12 GeV KEK-PS as a neutrino source and SK as the far detector. The distance between KEK and SK is 250 km , and the neutrino beam has an average energy of 1.4 GeV. The neutrinos are produced by charged pion decays and expected to be 99% pure ν_μ with an angular deviation $\leq 3 \text{ mrad}$. In order to measure the effects of oscillation we compare the ν_μ spectrum observed by SK to the one measured in the front detectors at the point of production.

Fig. 2(a) shows the Monte Carlo simulation of reconstructed neutrino spectra at SK for 1×10^{20} protons on target(*pot*). This corresponds to approximately 5 years of measurement. Oscillated spectra for four specific oscillation parameter sets are shown. The effects of oscillation are seen in the figures as a significant divergence from the spectra of the null oscillation case, which is given by open histograms.

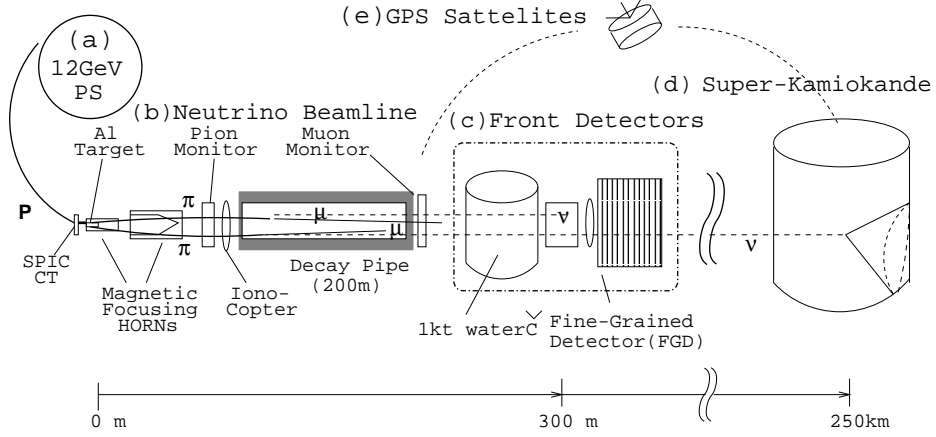


FIGURE 1. Schematic overview of the K2K experiment. (a) 12 GeV KEK-PS. A spill has 9 bunches in $1.1 \mu\text{sec}$, 7×10^{12} ppp for every 2.2 sec. (b) Neutrino beam line. Protons, bent to the direction of Kamioka in the “arc section” of the beam line, are injected into Aluminum target of $3\text{cm}\phi \times 66\text{cm}$, embedded in the 1st horn. The proton beam profile and strength before the target are measured by 2 SPICs and 2 CTs, respectively. Two horn magnets for π focusing, a gas Cherenkov counter for π momentum distribution measurement (π monitor), and ϕ -symmetry monitor (iono-copter) are in a target station. π s decay into μ and ν_μ in 200m of decay pipe filled with helium gas. The μ profile is measured by ionization chambers and a silicon pad detector located behind the beam dump (μ monitor). (c) Front detector system to measure neutrino beam properties at the production. It is composed of a SK-like water Cherenkov detector (1kt detector) and a fine-grained detector(FGD) for detailed study of neutrino interaction with water. (d) Super-Kamiokande(SK) as a far detector, 50 kt water Cherenkov detector under stable operation since 1996, 250 km downstream of the target. (e) The GPS system is used to look for events at SK during the KEK PS beam pulse. The precision of $\Delta(T_{\text{KEK}} - T_{\text{SK}})$ is within 300 nsec, calibrated by an atomic clock.

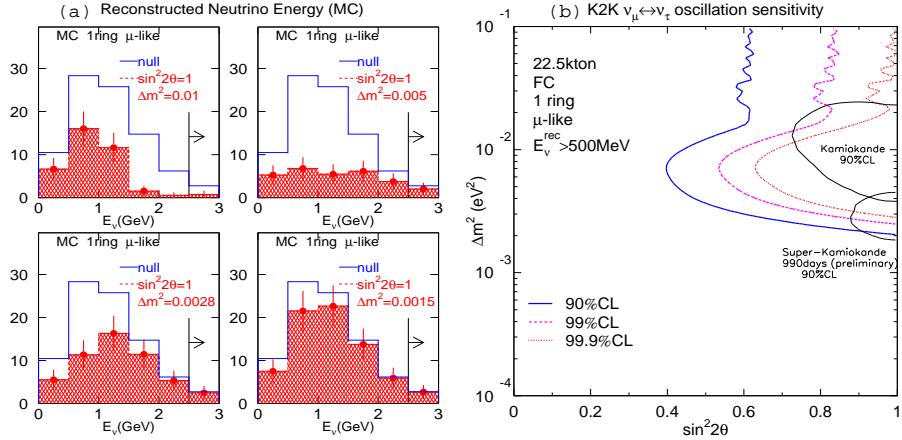
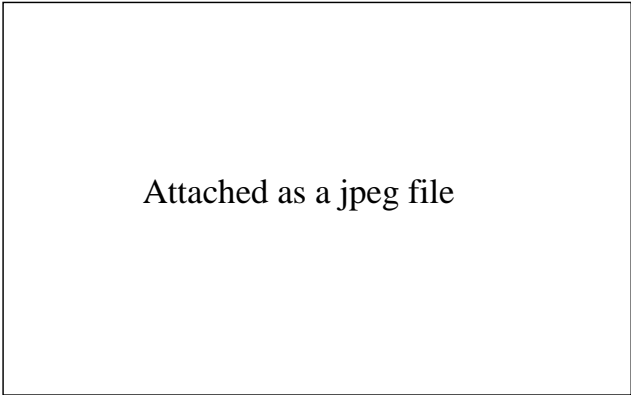


FIGURE 2. (a) Monte Carlo simulated reconstructed neutrino spectrum at SK, with four oscillation parameter sets. 10^{20} protons on target correspond to 190 neutrino interactions in the 22.5 kt SK inner fiducial volume in case of null oscillation. Plots are for 90 fully contained single-ring μ -like events. (b) Sensitivity plots of the K2K experiment for $\nu_\mu \leftrightarrow \nu_\tau$ oscillation.



Attached as a jpeg file

FIGURE 3. (a) Integrated *pot* and (b) *ppp* at the target, as functions of date from April 1999 to March 2000. Dates of SK fully-contained events are marked with arrows for 1999.

K2K's 90% confidence level sensitivity covers almost all of the 90% allowed regions obtained by Kamiokande and SK, as shown in Fig. 2(b).

Fig. 3 shows the record of protons on target. After the completion of the front detector construction in Feb. 1999, the fast extraction of protons for the experiment started on Feb. 3. On Mar. 4, the neutrino beam DAQ started with a horn current of 175 kA and with proton intensity of $3 \times 10^{12} ppp$. After engineering runs to study neutrino beam operations in April through May, stable data taking began in June with an aluminum target with $2cm\phi$, a horn current of 200 kA, and a proton intensity of $4.5 \times 10^{12} ppp$. After the summer shutdown, continuous data taking began again in November, this time with an aluminum target of $3cm\phi$ and a horn current of 250 kA with $5 \times 10^{12} ppp$. In 1999 we accumulated $7.2 \times 10^{18} pot$ in total.

OBSERVATION BY NEAR DETECTORS

The near detector system consists of a 1kt water Cherenkov detector(1kt) and a fine-grained detector(FGD). The latter consists of a scintillating fiber tracker(SFT) [2], plastic scintillator veto counters, an electromagnetic calorimeter of 600 lead glass blocks, and a muon ranger of 12 iron plates ($10cm \times 4 + 20cm \times 8$) with drift chambers(MUC). The SFT is composed of 19 layers of 6cm-thick water containers sandwiched with $20 \times (yy-xx)$ layers of $700\mu m\phi$ scintillating fibers.

1kt is used for normalizing predicted beam flux at SK. The fact that the two detectors are so similar cancels out systematic errors that would otherwise be present.

MUC contained events are used to check the stability of the neutrino beam. This is because the large fiducial volume mass of the MUC results in a very large event rate. The beam center is observed to be stable to within $1mrad$. In addition, spill by spill beam centering, monitored by the profile of the muons produced by pion-decay that penetrate the beam dump, was also found to be within $0.5mrad$.

Fig. 4(a) is an example of quasi-elastic(QE) neutrino event candidates with vertex

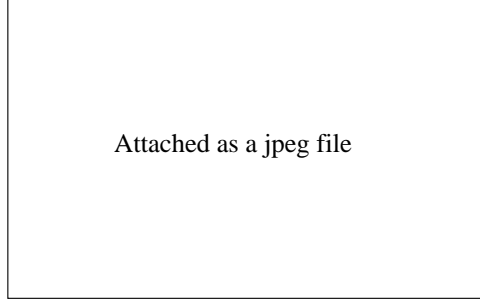


FIGURE 4. (a) A typical ν_μ event observed with the FGD. (b) Muon energy distribution for single track samples. (c) $\cos(\Delta\theta_P)$ distribution for 2 track samples. In (b)/(c), histograms show MC, where open area is for quasi-elastic events, and hatched area is for non-QE (charged current inelastic + neutral current) events.

in the SFT. The primary goal of the FGD is to reconstruct the neutrino spectrum by using QE samples. (b) shows the reconstructed muon energy distribution for single track events, and (c) is $\cos(\Delta\theta_P)$ distribution for 2 track samples, where $\Delta\theta_P$ is angular difference between reconstructed proton track and that calculated from muon momentum. The single track samples and 2 track samples with $\cos(\Delta\theta_P) \geq 0.95$ contain a large fraction of QE events, $\sim 60\%$ and $\sim 80\%$ respectively.

We also study the ratio of inelastic events to QE events, in order to reduce the uncertainty of the calculated neutrino interaction cross section to less than 10%. This information is important not only for K2K, but also for the SK atmospheric neutrino analyses. Table 1 gives summary of the front detector results. Event numbers normalized by MC predictions agree very well to each other.

NEUTRINO EVENTS IN SUPER-KAMIOKANDE

On June 19, 1999, 18:42(JST), K2K observed its first neutrino event due to the KEK neutrino beam in Super-Kamiokande. This was the first time that an artificially produced particle was detected after traveling such a large distance. Fig. 5(c) shows ΔT distributions at each reduction step, where ΔT is the time difference between SK event and KEK beam pulse, taking time of flight between

TABLE 1. Summary of the near detector observation.

	Mass(t)		$pot(10^{18})$	Events	Data/MC $\pm st.\pm sys.$
1kt	50.3	June	2.03	8,157	$0.83\pm.01\pm.07$
		November	2.62	11,337	$0.84\pm.01\pm.11$
MUC contained	445.	June	3.02	27,985	$0.83\pm.01\pm.11$
		November	2.75	28,077	$0.86\pm.01\pm.11$
SFT+MUC	4.9	June	2.28	315	$0.83\pm.05\pm_{.09}^{.08}$
		November	1.94	347	$0.86\pm.05\pm_{.09}^{.08}$

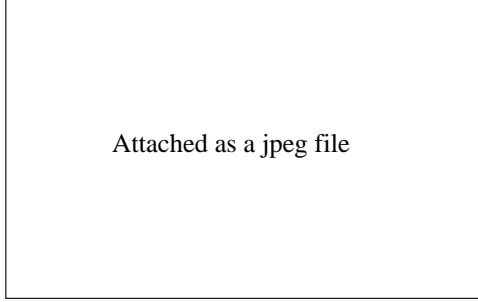


FIGURE 5. SK fully contained event examples (a) the 1st event in June, and (b) in November. (c) ΔT ($\equiv T_{SK} - T_{KEK} - T_{T.O.F.}$) distributions at each reduction stage: $\pm 500\mu sec$ time cut, (1) μ -decay electron cut (2) high energy trigger condition (3) inner counter total $p.e.$ cut $200 < Q_{TOT} < 50,000 p.e.$, and (4) outer detector cut.

KEK and SK into account. It is obtained by GPS within the precision of $300\text{ }nsec$. During the period of running we have 6 events within $1.3\mu sec$ time window, 3 of which are within $22.5kt$ fiducial volume (vertex distance from wall $\geq 2m$).

We can estimate the number (N_{SK}^{pred}) using the observed number of events at $1kt(N_{KEK})$: $N_{SK}^{pred} = (N_{KEK}/\epsilon_{KEK}) \cdot R \cdot \epsilon_{SK}$, where R is a factor of extrapolation from KEK to SK, ϵ_{KEK} and ϵ_{SK} are the detection efficiency of $1kt$ and SK, respectively. Since the target material (water) is common and the systematic uncertainty due to the cross section cancels, the value of R depends mostly on the flux ratio between SK and KEK, whose uncertainty is $^{+8\%}_{-10\%}$. N_{SK}^{pred} was estimated to be $12.3^{+1.7}_{-1.9}$ in total. Table 2 summarizes these numbers, with expectations for the case of three typical Δm^2 with $\sin^2(2\theta) = 1$. We will accumulate $> 2 \times 10^{19} pot$ in this summer, leading to an increase in the statistical power of these results.

REFERENCES

1. Obayashi, Y., *this conference*.
2. Suzuki, A. *et al*, to be published in *Nucl. Instrum. Methods A*, hep-ex/0004024.

TABLE 2. Summary of SK events. Fully-Contained(FC) are events with the significant light detected in the inner detector only. Outer Detector(OD) events, with light detected in the outer detector is also tabulated for reference (systematic uncertainty $\sim 40\%$).

	Data	No oscillation	$\Delta m^2 = 3 \times 10^{-3}$	5×10^{-3}	$7 \times 10^{-3} (eV)^2$
FC in fiducial	3	$12.3^{+1.7}_{-1.9}$	8.0	5.4	4.6
out of fiducial	3	$5.5^{+1.1}_{-1.2}$	3.5	2.4	2.1
OD contained	4	8.7 ± 3.3	5.5	3.5	2.9
(inner crossing)	2	4.2 ± 1.6	3.2	2.0	1.3

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